# 1. Solar Orbiter - Helioseismology

With the advent of helioseismology from space, our knowledge of the solar interior has made considerable progress. The Michelson Doppler Imager (MDI) onboard the ESA/NASA satellite SOHO has provided helioseismic data of extreme precision. Large-scale differential rotation has been mapped in most of the convection zone, and small temporal variations in the zonal flows beneath the Sun's surface have been detected as the present activity cycle unfolds. There have been unexpected and still controvertial discoveries, such as a buried jet-like flow and a surprisingly slow rotation rate at high latitudes (Fig 1). To complement techniques of global seismology, which have no resolution in longitude and are unable to distinguish the northern from the southern hemisphere, recent techniques of local helioseismology are being developed. In particular, time-distance helioseismology gives the opportunity to make 3D tomographic maps of the subphotospheric temperature inhomogeneities, magnetic field and flows. An important result concerns the observation at depth of the poleward meridional circulation (Fig 1b).

Solar Orbiter offers a unique opportunity to learn about the polar regions of the Sun, which remain largely unexplored. The main objective will be to

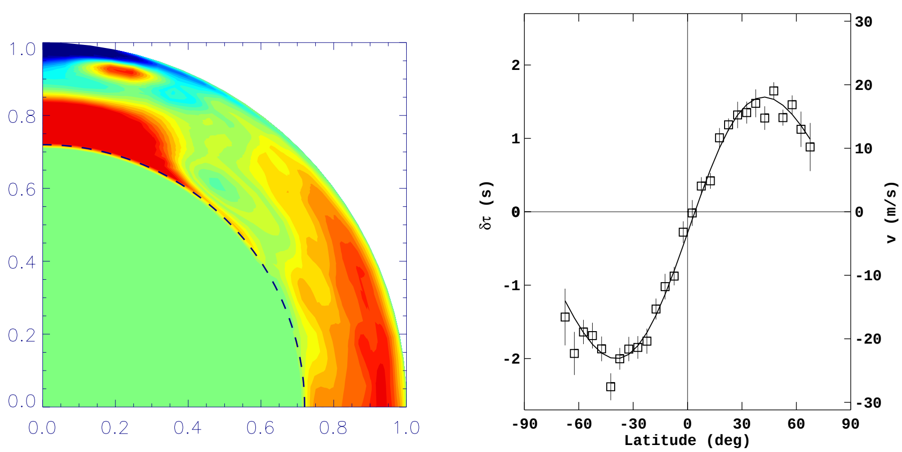


**Figure 1.** (**a**) Rotation rate in the convection zone after substraction of a smooth background. Blue (red) indicates slower (faster) rotation than average. Note the slow near-surface rotation at high latitudes, and the jet stream at latitude 75°. From Schou et al (1998). (**b**) Meridional circulation measured by time-distance helioseismology as a function of latitude. The scale on the left vertical axis gives the travel time difference in seconds between waves travelling in the southward and northward directions. On the right axis is the corresponding velocity, which is an average in the 34 Mm below the surface. From Giles et al (1998)

map the flows near the poles using time-distance helioseismology. One week of data is enough to derive the rotation rate in the upper convection zone, and confirm or refute the existence of the high-speed jet at latitude 75°. We will also be able to study the convergence at the pole of the meridional flow, and to observe how and where the solar plasma dives back into the Sun. It will be of great interest to monitor the temporal evolution of the flows over the 5 years covered by the mission. Convective motions, in particular supergranulation, will also be studied. Figure (2b) shows an incomplete view of the north pole simulated with MDI Dopplergrams, where supergranular cells can easily be identified. Figure (2a) demonstrates that only a few hours of observations are necessary to make time-distance measurements of supergranules.

A more challenging project would be to probe the tachocline, a shear layer at the base of the convection zone, where the solar dynamo is presumed to be at work. There is some indication in today's data that the depth of the tachocline may be smaller at high latitude. It is important to keep in mind that local diagnotics of the solar interior, which include time-distance helioseismology, seismic holography and ring diagrams, are still under development today and are likely to be much more advanced ten years from now.

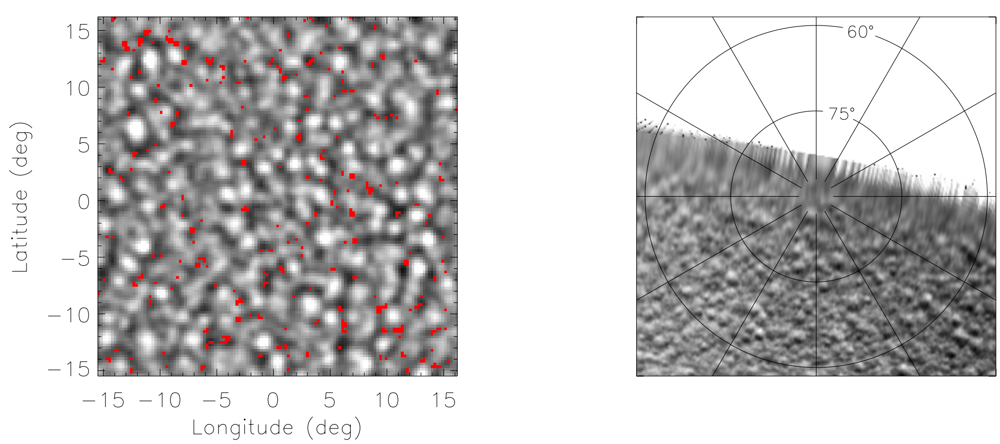


**Figure 2.** (**a**) Map of the horizontal divergence of the flow field in the 2 Mm beneath the surface. White shades indicate outflow. The time-distance data are averaged over 8.5 hours. Magnetic field signal is overlaid (magnitude greater than 15 Gauss). From Duvall & Gizon (2000). (**b**) A view of the North pole on 19 Sept 1996 when $B_0 = 7.17°$ (stereographic projection). MDI Doppler images have been averaged over 8 hours. Solar Orbiter will provide a complete picture.

## 2. Requirements ?

We need maximum coverage of the polar region at a given time. The field of view needs to cover a large part of the Sun. Reasons: (1) spatial averaging to measure large-scale flows, (2) if we want to probe deep (say base of the convection zone), we need to make travel-time measurements between points separated by a large distance (say 45 deg). The deeper we want to probe, the bigger the field of view.

The resolution probably needs to be comparable to MDI full-disk. Since we wish to study regions at high latitudes it may need to be even better. Idealy, we'd like to see ridges to at least l=1500. So 1.5 Mm/pix would be great. But if the resolution is twice less, it is still acceptable. The bottom line is 6 Mm/pix (not worth it below that resolution).

Note. It is very important to make extensive ground tests of the instrument before flying it. Some MDI tests were not good enough (plate scale, optical distorsions, MTF...) and calibration problems are now difficult to solve. http://soi.stanford.edu/data/cal/all_data.html#plate_scale.

## 3. Bibliography

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